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THE variability of soil profiles[1] causes difficulty in the preparation of a soils map for forestry purposes. The differences from profile to profile are apt to bewilder the beginner unless he understands the reasons for them. A very nice example of this class of soils problem was encountered about a year ago in the subdivision of the Dukes Experimental Forest of the Lake States Forest Experiment Station.

This forest is located near Marquette, Michigan, and is in the so-called Podsol soil zone of the United States. ''Podsol'' is a Russian word meaning ash-like, and is a term applied to a certain group of soils in cool, moist climates which have a white or gray layer in the upper part of the profile. This white or gray horizon is more or less characteristic of soils in temperate regions where precipitation is greater than evaporation, resulting in a downward percolation of much ground water and the translocation of soluble minerals from the upper soil layers to lower ones. The white or gray horizon is insoluble quartz sand and hence its color. It should be explained, however, that all podsol soils do not have a light colored upper horizon.

Although the Dukes Experimental Forest is located in a zone of well-developed podsol, there are several soil types found on the area. In some cases these types are variations of true podsol, and in others distinctly separate from it. Since the correctness and usefulness of the forest subdivision depended upon the general accuracy of the soil map, it was necessary to determine the cause and the limits of the variations not only between different soil types but also within the same one.

Field investigations showed that the variability of the soil profile is quite often traceable to local climate, which, in most cases, means differences in topography, less commonly to the differences in the mineral constitutents of the soil or to the effect of the forest vegetation. This information furnished the starting place for the division of the area into soil types. Random lines were run through the woods so as to separate the hills from the creek bottoms, the swamps from the flats, etc. In

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[1] "By the term profile is designated everything that is presented to the eye of the observer in a vertical cut through the soil exposing its various horizons." (From C. F. Marbut's translation of "The Great Soil Groups of the World and Their Development," from the German. 1927)

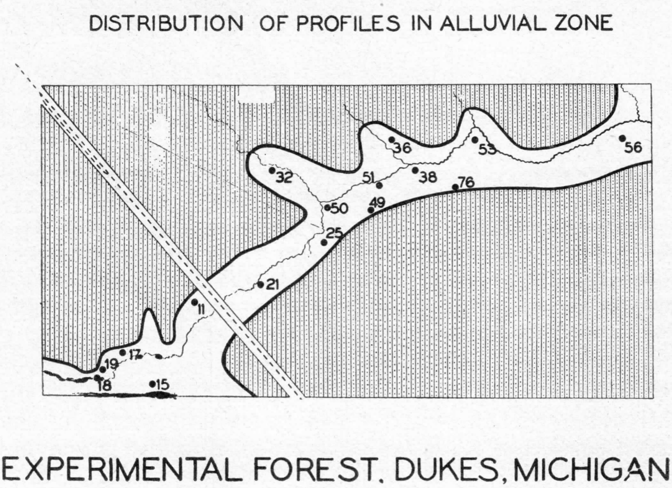

Figure 1. Distribution of soil profiles in the Alluvial Zone (unshaded area). Virgin forest portion of the Upper Peninsula Experiment Forest, Dukes, Michigan.

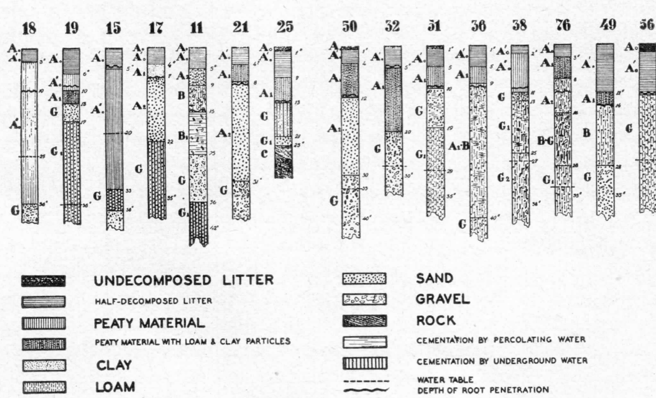

Figure 2. Variations in the physical-chemical character of the Alluvial Zone.

other words, the initial step in the preparation of a soils map for forest management consisted of subdividing the topography. Once this had been done the problem was to determine whether the same soil type occurred in areas having similar topography.

Observations demonstrated that areas having essentially the same topography were not always characterized by the same soil type. Thus, DARK FOREST SOIL, a podsol with a well-developed gray horizon, and PODSOL with a gray or white leached upper layer both occurred in the upland portions of the forest. Similarly, two types of WOODY PEAT were mapped in the swamps. One type was characterized by WOODY PEAT resting directly upon glacial till. The other was underlain by older deposits of fibrous remains of plants (FIBROUS PEAT). A comparison of typical profiles for DARK FOREST SOIL, PODSOL, and WOODY PEAT showed striking dissimilarities. In contrast, a comparison of a series of profiles for any one of the three brought out the lack of striking variations. It was of interest to discover that the average height of dominant sugar maple trees growing upon PODSOL with a pronounced gray layer was from 8 to 10 feet less than for trees growing upon DARK FOREST SOIL.

A real problem was encountered when an attempt was made to map the soils in the part of the forest occupying creek valleys and flats. Here it was found that profiles varied greatly within relatively short distances. The task of mapping these areas became one of grouping soils with similar but not identical profiles.

No better illustration of the variation of soil profiles within the same topographic unit can be had than in the so-called Alluvial Zone of the Dukes Forest (Figure 1). This zone occupies an area which is seasonally flooded by the large creek draining it and is characterized by a year-round high-water table.

A series of profiles were dug along this narrow flood plain and such features as the depth of humus layers, the color, texture, and structure of the mineral horizons, root penetration of trees, height of water table, and character of the unweathered substrata were noted. The lack of uniformity of the profiles raised the question of how the differences between them should be indicated on the soil map. It was apparent that all the variations could not be shown unless a map was drawn having about the same scale as the ground itself. As a matter of fact, the entire Alluvial Zone was mapped as PEATY CLAY or MUCK. The justification for this typing will be made clear by an analysis of the conditions attending the formation of PEATY CLAY soils.

In the first place, field examinations revealed that MUCK or PEATY CLAY soils occupy the low, poorly drained portions of the experimental forest, such as sunken plains, basins, and valleys. Using this information as a starting place, several other fundamental facts were evolved. It was found, for example, that the composition of the parent substrata played a very small part in the development of PEATY CLAY soils which were primarily a result of excessive moisture conditions. Similarly, by the comparison of numerous profile descriptions, it was demonstrated that most of the PEATY CLAY soils of the forest were characterized by a half-organic-half-inorganic A_1[2] horizon of always moist, steel, or bluish gray admixture of peat and clay particles. This peculiarity served as the basis for the name of the soil. It was also interesting to note that PEATY CLAY soils of the experimental tract were formed either upon morainic substratus or upon pure alluvial sand, although in one case PEATY CLAY soil was found resting upon bedrock or calcareous sandstone. This profile could be distinguished as a definite morphological variation of ordinary MUCK by the presence of much calcium in all mineral horizons which reacted violently with hydrochloric acid when the soil was in a dry condition.

Insofar that the Alluvial Zone of the Dukes Forest occupied a low, poorly drained valley and many of the profiles dug within its limits answered the description of typical PEATY CLAY soils, it was decided to map the entire area as a single soil type providing the presence of small areas of other soil types could be made to fit into the classification scheme. This necessitated proof of the genetic relationship of the various profiles dug in the Alluvial Belt.

The justification for grouping all the soils of the Alluvial Zone into a single type is found in the basic similarities of profiles (Figure 2).

Take, for example, the depth of superficial dead organic or A_0 horizons. One profile (Profile 76) has a humus layer aggregating 3 inches; three more (Profiles 17, 21, and 50) each have a total accumulation of 4 inches of humus; another four (Profiles 11, 32, 36, and 51) an A_0 5 inches deep; and finally, another set of five (Profiles 19, 25, 38, 49, and 56) approach the realm of true peats in that they have superficial dead organic horizons varying from 7 to 11 inches in thickness. The extremes in the

[2] One of the more conventional systems of describing the various layers or horizons of the soil profile is their designation by letters. A common method is to letter the horizons A, B, and C. As used here, superficial dead organic horizons are referred to as the A_0; horizons in which there is an admixture of organic and inorganic particles, the A_1; and the white or gray leached horizon of a PODSOL profile, the A_2. The B horizons of a PODSOL soil are those in which the materials leached out from the upper layers by either chemical or physical processes are redeposited. They are designated here by the letters B and B_1, depending upon their depth, color, structure, and texture. Unweathered substrata are symbolized by the letter C. Horizons formed by the seasonal fluctuations of the water table are indicated by the letters G, G_1, and G_2. The morphology of these horizons is explained in the text.

progressive deepening of the humus horizons are seen in Profiles 15 and 18, which represent true peats in which organic remains of plants and trees have piled up to a depth of 33 and 36 inches respectively. All other profiles (Figure 2) fall somewhere between these two in regard to depth of the A_0 layers. Here, then, is a common characteristic of all the profiles of the Alluvial belt which serves to assign them to a single group. The correctness of this grouping becomes obvious when the cause for the accumulation of humus is sought and found to be slow decomposition under the conditions of excessive moisture.

By continuing this analysis other fundamental qualities of MUCK soils may be accounted for. It is stated, for instance, that the PEATY CLAY soils of the forest are underlain by substrata of either glacial till, alluvial sand, or bed rock. Each of the fifteen profiles under discussion (Figure 2) fall into one of these three groups. It is also stated that true PEATY CLAY soils usually are characterized by a well-defined plastic, moist, half-organic-half-inorganic, steel, or bluish gray A_1 horizon. Ten out of a total of fifteen profiles in the Alluvial Zone meet this requirement. Three of those which do not are distinctively separate from MUCK soil genetically, two being WOODY PEAT and the third SWAMPY PODSOL. The remaining two are the exceptions which disprove the rule, both answering all the requirements of MUCK excepting the physical-chemical nature of the A_1 horizon.

The final and most complete argument for mapping the soils of the Alluvial belt as a single type can be traced to the so-called "Glei" horizons. Glei is another term borrowed from Russian soil science.

Glei horizons are formed by the rise and fall of the water table in semi-swampy areas. The relative height of the water table in these areas depends upon the season of the year. After rainy spells, it is near the surface (depth of root penetration as shown in Figure 2 marks the upper limits). During the drier seasons of the year, on the other hand, the water table falls and more normal moisture conditions prevail. These seasonal trends, going on year after year, result in a definite morphology of the soil. Morphologically, these variations assume different forms. Sometimes clay and silt particles are carried up by the water at its highest ebb and precipitated upon its recession during the drier seasons. A layer of almost pure clay is formed in this way. In other cases, the movement of the water table results in a concentration of mineral salts which sometimes causes the soil separates to cement into a hardpan mass. Again, the horizons may be characterized by numerous rust-red, brownish, greenish, and bluish flakes or agglutinations, colors, commonly found in soils of insufficient aeration, resulting in reduction processes and the formation of ferrous instead of the more usual ferric compounds. Profile 51 illustrates this point.

Profile 51. PEATY CLAY soil formed upon a substratum of morainic drift. The forest stand consists of an admixture of northern white cedar, yellow birch, and balsam fir.

A^1_0—1.0 inch of undecomposed leaves and litter.

A^2_0—4.0 inches of half-decomposed, dark brown organic matter having a granular structure.

A_1—5.0 inches of plastic reddish-gray, sometimes steel or bluish half-organic-half-inorganic clayey horizon. Always moist.

G_1—9.0 inches of compact yellowish loamy sand containing gravel. Clay particles are present. Painted black with humus compounds. In some places reddish, brownish, or greenish agglutinations can be seen. Wet.

G_2—17.0 inches of slightly compacted loamy sand. Water table at depth of 29 inches.

Without a single exception, all of the profiles (Figure 2) of the Alluvial Zone are characterized by one or more G horizons and are, therefore, morphological variations of Glei soils. Consequently, these profiles may be included within the same soil type without any great transgression of the basic fundamentals of separating soils into groups of closely related genetic types.

Before passing over the technical discussion of the soils of the Alluvial Zone, it should be pointed out that the A_2 horizon of Profiles 17, 21, and 50 is not the white or gray layer of a Podsol Profile but is instead the first strictly mineral horizon of the genetically undeveloped profile of alluvial sand. In the way of a general summary the following thing may be said of the soils of the Alluvial Belt.

PEATY CLAY soil very rarely occupies a large, contiguous area, but, as a rule, its, distribution is broken by island-like formations of SWAMPY PODSOL[3] or WOODY PEAT, resulting from small changes in relief and drainage. The Alluvial Zone of the virgin forest portion of the Dukes Experimental Foret serves as a concrete illustration of this variability. Upon the basis of the distribution of the soil profiles in this zone and the variability which these profiles show, it is possible to say that: (1) PEATY CLAY soil formed upon pure alluvial sand occupies low places along the banks of the watercourses, and

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[3] Sometimes PODSOL soil is found in areas of insufficient drainage. This soil is like ordinary PODSOL in that it has a gray leached A_2 layer, but differs from it by the presence of water-formed or Glei horizons in the lower part of the profile. A soil of this general description is referred to here as SWAMPY PODSOL.

usually confines itself to a narrow strip, at the most not more than 100 to 150 feet wide. (2) PEATY CLAY soil formed upon skeleton glacial drift covers about three-fourths of the total area in places of insufficient drainage. (3) WOODY PEAT forms tongues or small lakes in those places where drainage is completely absent. (4) SWAMPY PODSOL replaces PEATY CLAY soil upon raised, island-like hummocks formed from the accumulation of morainic drift. (5) The abnormal depth of the superficial dead organic layer and the presence of Glei horizons is a common feature of all the soils in the belt. (6) In ten cases out of a total of twelve MUCK soil was identified by the similarity of the A_1 horizon.

Due to the variations in soil, the forest types upon PEATY CLAY also vary widely from almost pure hardwoods, hardwood to mixed coniferous stands of northern white cedar, black spruce, and balsam fir. In those places where there is a constant movement of the water table, as along streams, most tree species are replaced by alder.

The thick layer of water-logged organic and half-organic-half inorganic material forming the A_0 and A_1 horizons of PEATY CLAY soil discourages the establishment of natural reproduction of the more valuable upland tree species, such as sugar maple, and prevents rapid growth of all species.

A a general rule, these soils support an abundance of water-loving vegetation.

There is, perhaps, no other problem in forest research that is quite so fascinating as the study of soil and its relation to the growth and composition of the forest. The charm of the work lies in the intricacy of the thing itself. It is not always so easy to fit a puzzle together piece by piece, but usually it can be done and the unassembled units always remain as an open challenge to the man with an investigative type of mind. Therein lies the magnetic appeal of the study and classification of the soil.[4]

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[4] The writer owes much to Dr. S. A. Wilde who supervised the field work and the preparation of the manuscript from which this article was prepared.